Thermal Barrier Coating Lifetimes for High Temperature, Low Density Superalloys

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Outline

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- The Benefits of Low Density, Single-Crystal (LDS) Superalloys
- Purpose of current study

II. Experimental
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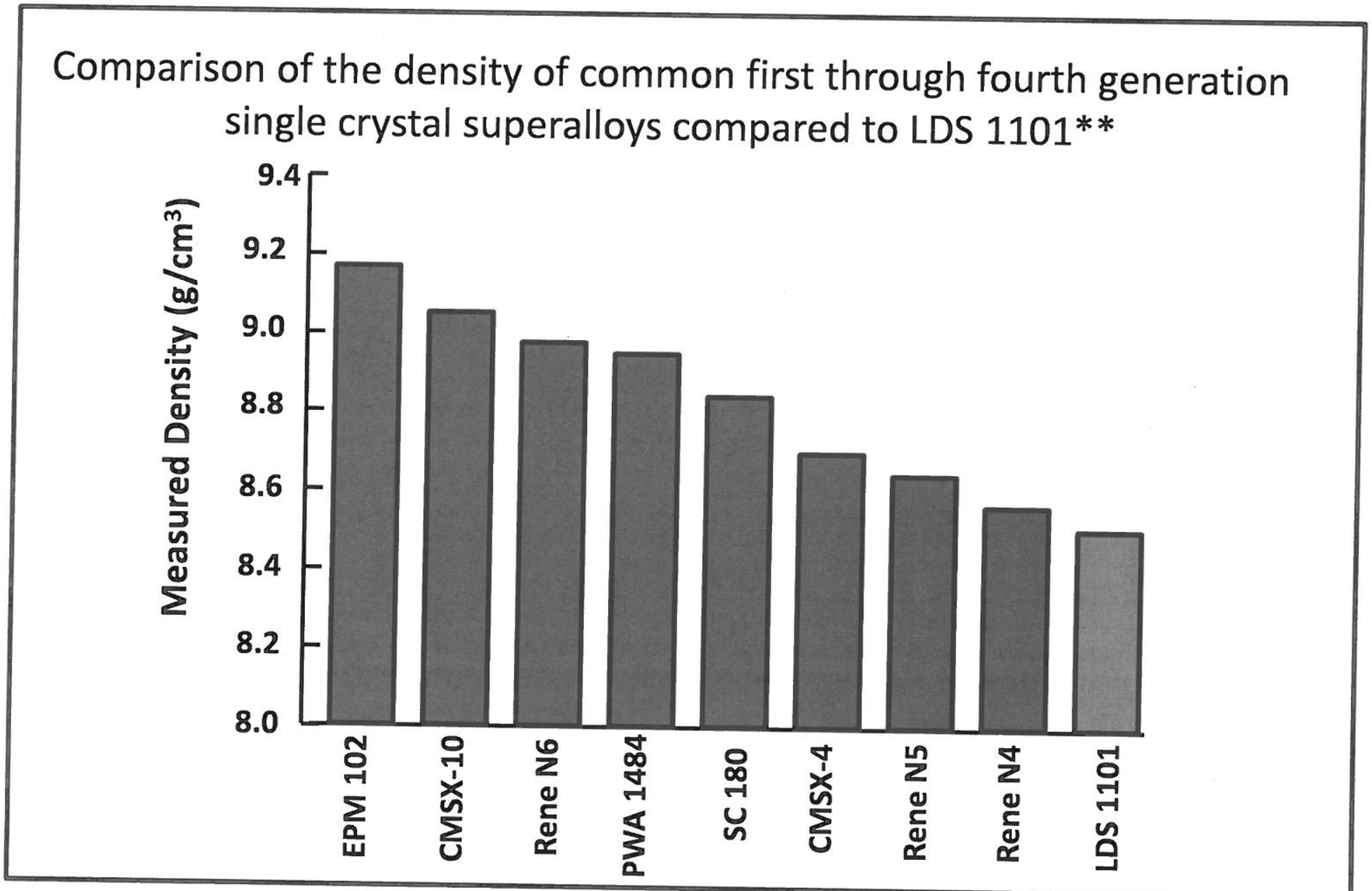
- Bond coats
- 7YSZ top coat
- Cyclic furnace testing

III. Results
- TBC lifetimes
- Fracture morphologies

IV. Conclusions

Why LDS alloys?

"A reduction in the turbine blade weight has a cascading effect throughout the entire rotor (disk, hub, and shaft) and to non-rotating support structures, traditionally achieving a total engine weight savings of 8 to 10 times the blade weight savings."*



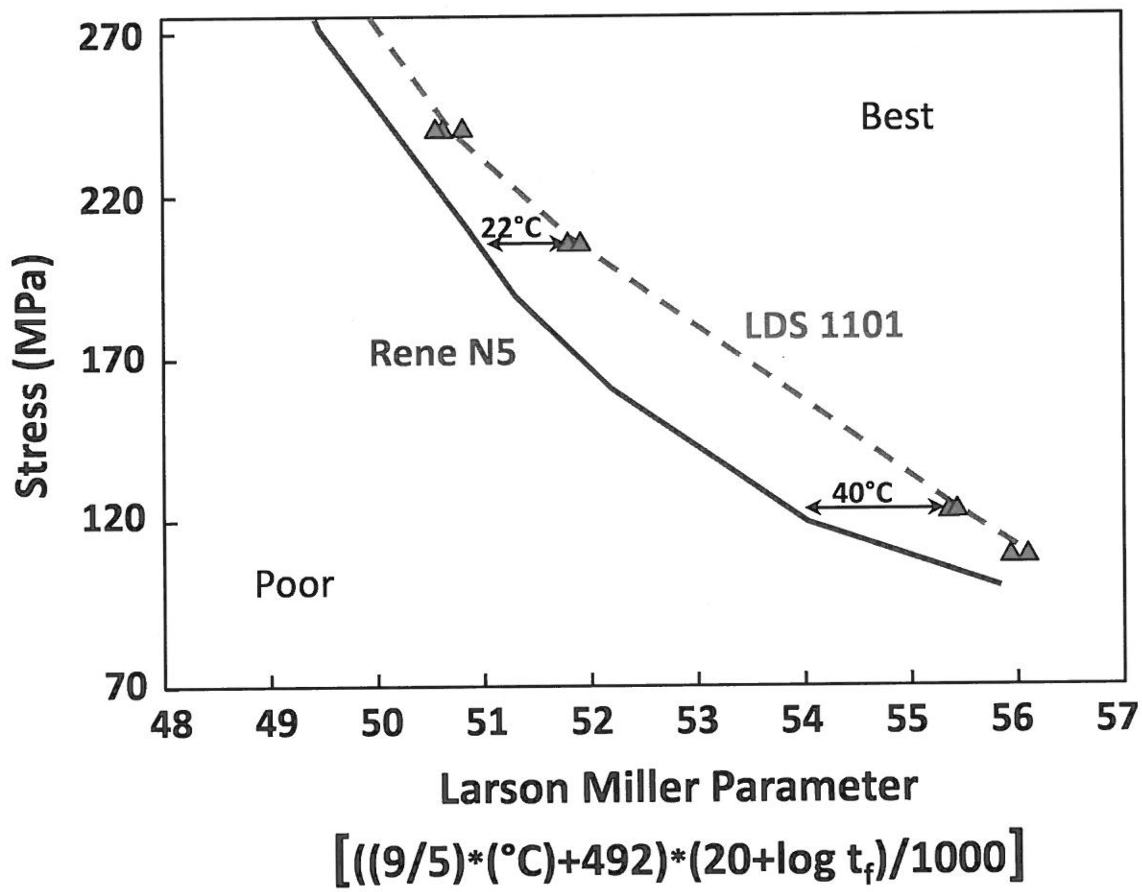
* Source: Dr. Hugh R. Gray, NASA Glenn Research Center, Sept. 2001

** Source: R. A. MacKay, et al., "A New Approach of Designing Superalloys for Low Density," JOM, Jan. 2010

Introduction: Benefits of Low Density, Single-Crystal (LDS) Superalloys

Creep Strength

Improved creep strength over a second generation superalloy *

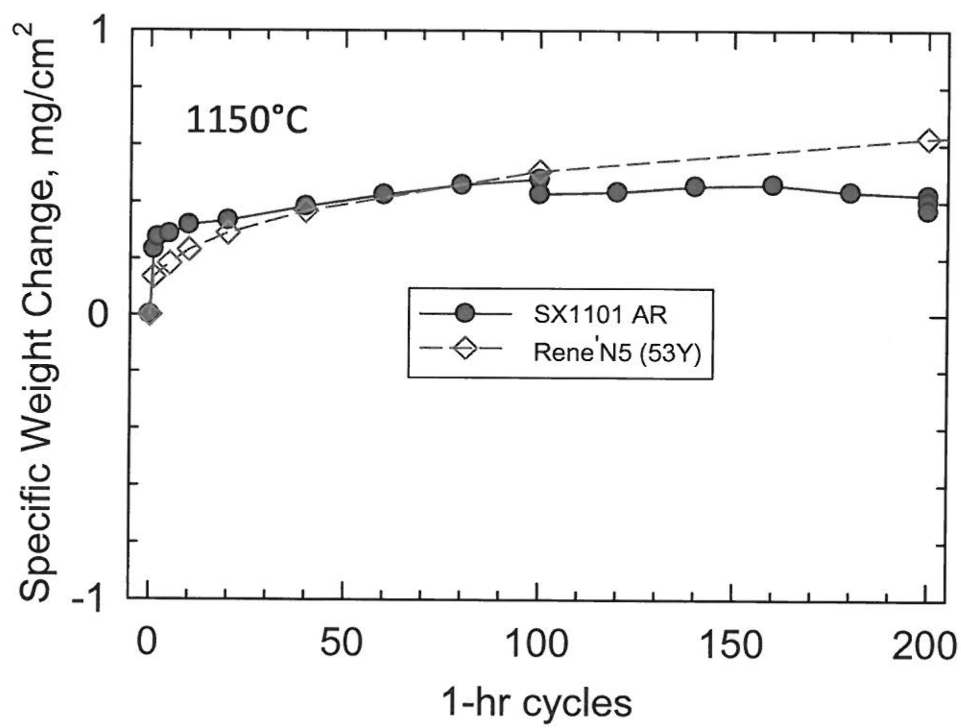


* Source: R. A. MacKay, et al., "A New Approach of Designing Superalloys for Low Density," JOM, Jan. 2010

Introduction: Benefits of Low Density, Single-Crystal (LDS) Superalloys

Oxidation Behavior

Similar cyclic oxidation behavior between LDS 1101 (+Y) and Rene N5 (+Y)*



* Source: R. A. MacKay, et al., "Alloy Design Challenge: Development of Low Density Superalloys for Turbine Blade Applications", NASA TM-2009-215819

Introduction

Turbine blades require environmental coatings, both for oxidation (e.g., Pt aluminides) and thermal protection (Thermal Barrier Coatings - TBC's)

Purpose:

Determine if there is a debit in the environmental life of SOA coatings on LDS superalloys

1. Cyclic oxidation behavior (metallic coatings)
2. → *Thermal Barrier Coating lifetimes*

Approach:

Compare the TBC lifetimes for LDS and CMSX-4 alloys

- LDS tested with and without Hf additions

Experimental

Alloy Compositions

(weight percent)

Alloy	Ni	Al	Cr	Co	Mo	Re	Ta	W	Ti	Hf	Y	S (ppmw)	Other
LDS-1101†	63.1	6.0	4.7	9.9	7.1	3.0	6.2	–	–	–	0.0050-0.0193	4.1	0.0035 B, 0.016 C
LDS-1101 +Hf†	61.7	6.1	5.0	10.0	7.3	3.1	6.5	–	–	0.19	0.0076-0.0079	0.87	0.024 C
CMSX-4	60.6	5.9	6.4	9.6	0.6	2.9	6.6	6.3	1.0	0.10	0.014†	NA	NA

† Actual compositions

NA - Not analyzed

Bond coats

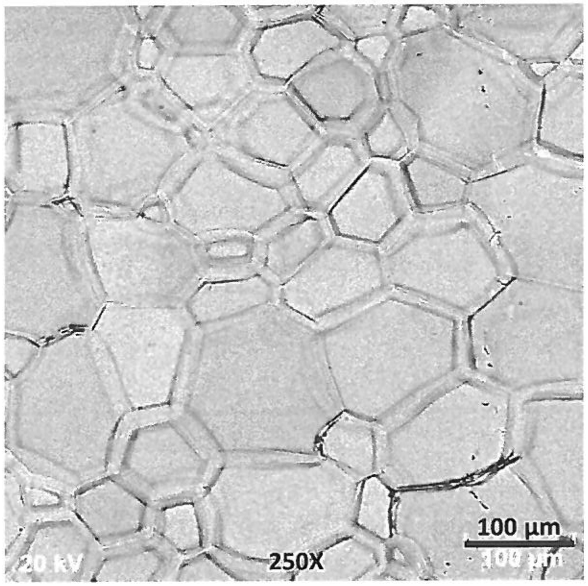
LDS 1101, LDS 1101+Hf, CMSX-4: Pt aluminide (MDC 150L)*

LDS 1101: Pt only (7.5 ± 1.8 μm thick, annealed 1 hr at 1150°C in Ar)*

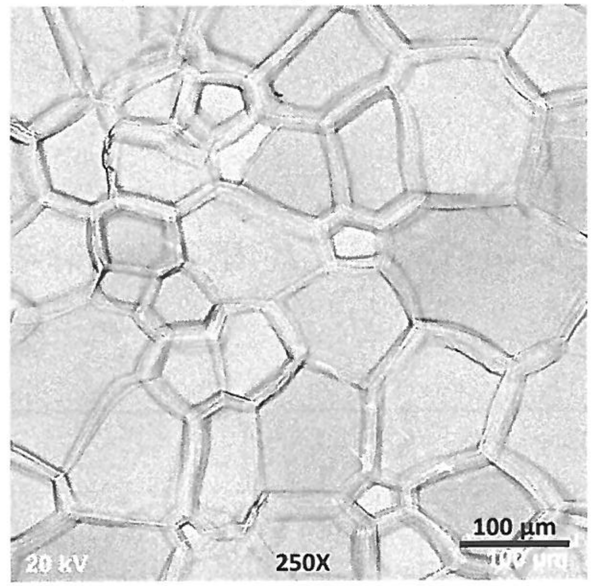
* Deposited by Alcoa Howmet, Whitehall, MI

Bond coat surface prior to top coat deposition

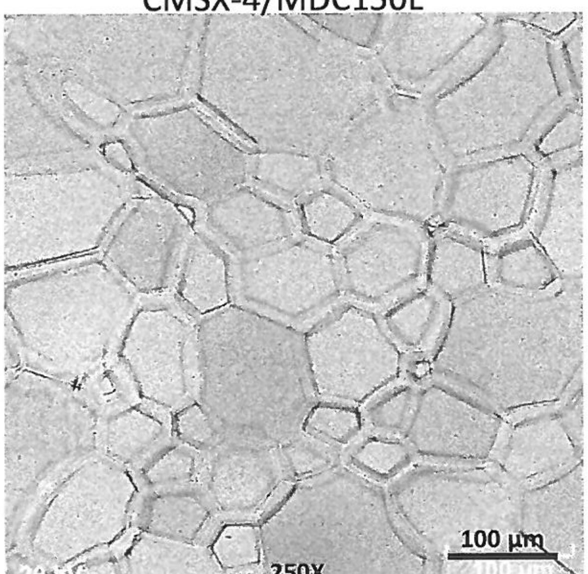
LDS 1101/MDC150L



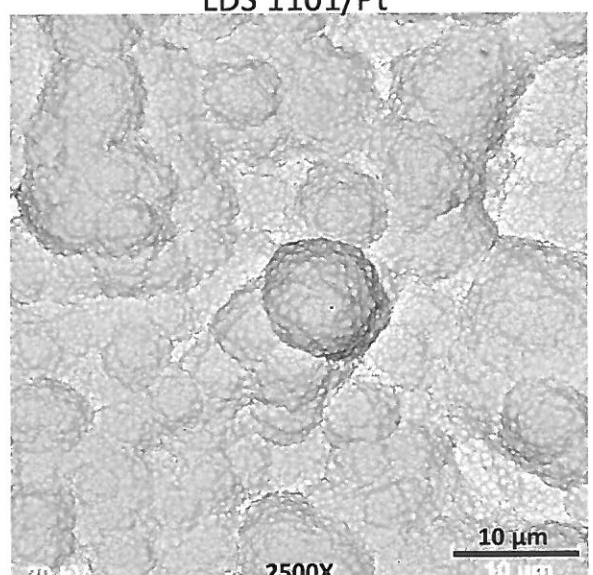
LDS 1101+Hf/MDC150L



CMSX-4/MDC150L



LDS 1101/Pt



10X higher magnification

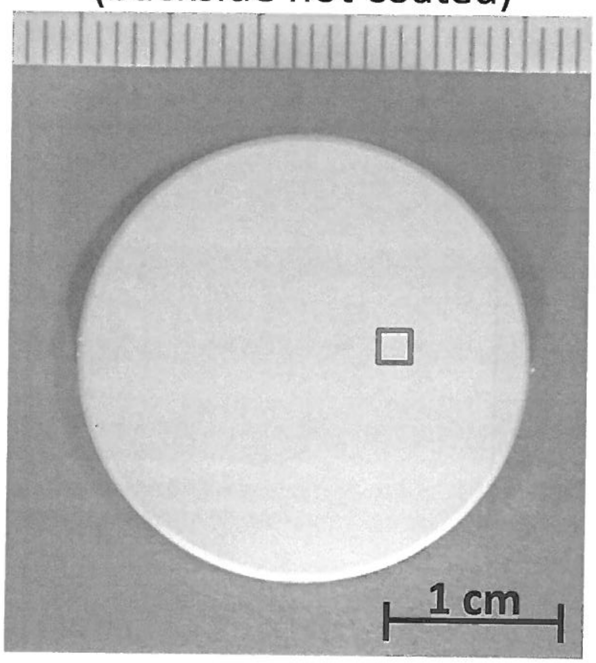
No significant difference in the typical ridge morphology of the Pt-aluminide coatings

Experimental

Sample Geometry

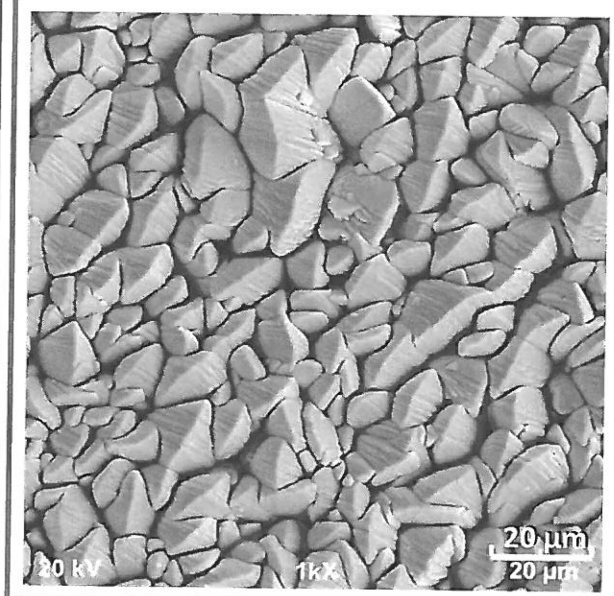
Standard “TBC button”
2.54 cm (1”) diameter
0.3175 cm (1/8”) thick

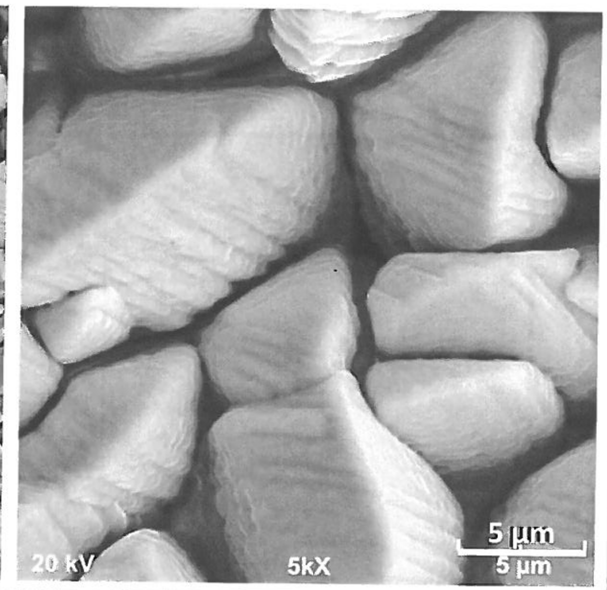
As-coated button
(backside not coated)



Top coat

EB-PVD ZrO_2-7wt.% Y_2O_3 (7YSZ)
Supplied by GE Aviation, Evendale, OH





Experimental

Sample Matrix

Substrate	Bond Coat	Top Coat	#
LDS 1101	MDC150L	7YSZ	3
LDS 1101+Hf	MDC150L	7YSZ	3
CMSX-4	MDC150L	7YSZ	3
LDS 1101	Pt only	7YSZ	3

Cyclic Furnace Test

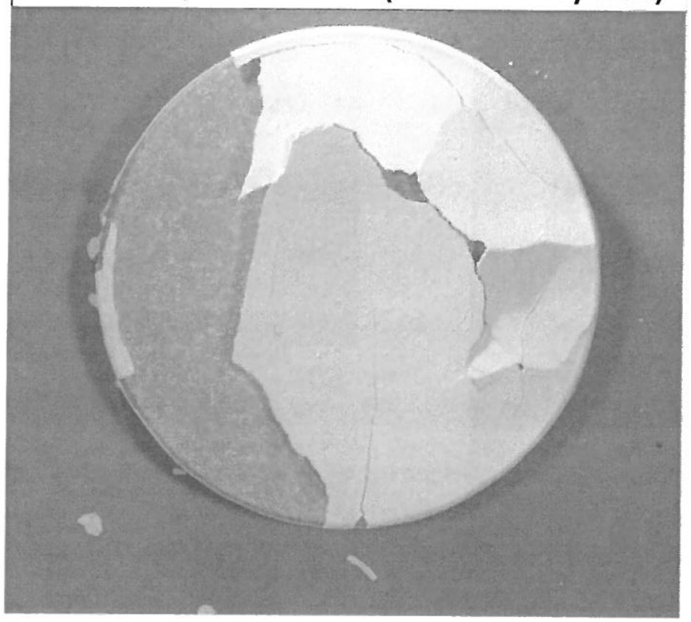
1 - hr exposure at 1035°C (1895°F) in air, minimum 20 minute cool.
Inspection every 20 cycles

All samples tested at the same time in a large capacity, bottom loading muffle furnace

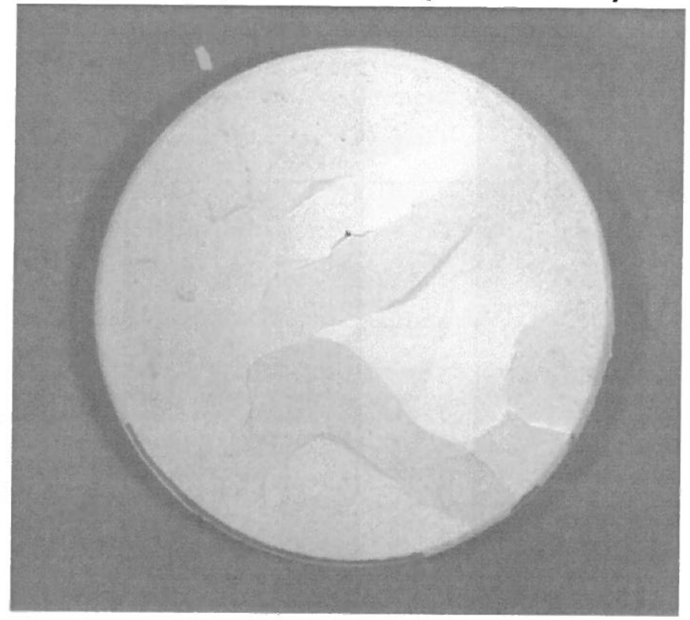
Failure criterion: ~10%-20% spall or visually obvious top coat delamination

Results: Typical macro failure morphology

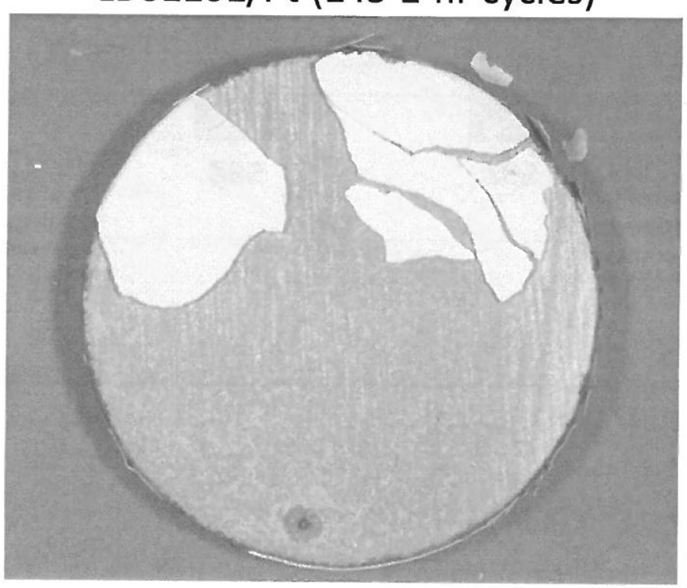
LDS1101/MDC150L (105 1-hr cycles)



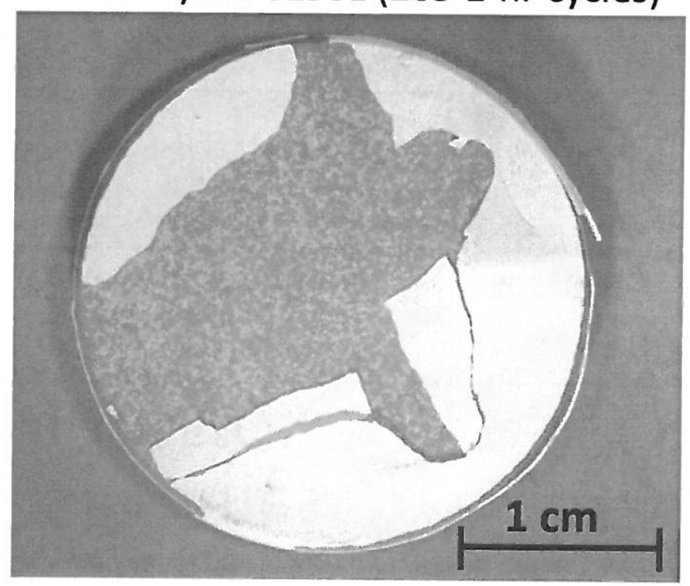
LDS1101+Hf/MDC150L (285 1-hr cycles)



LDS1101/Pt (145 1-hr cycles)

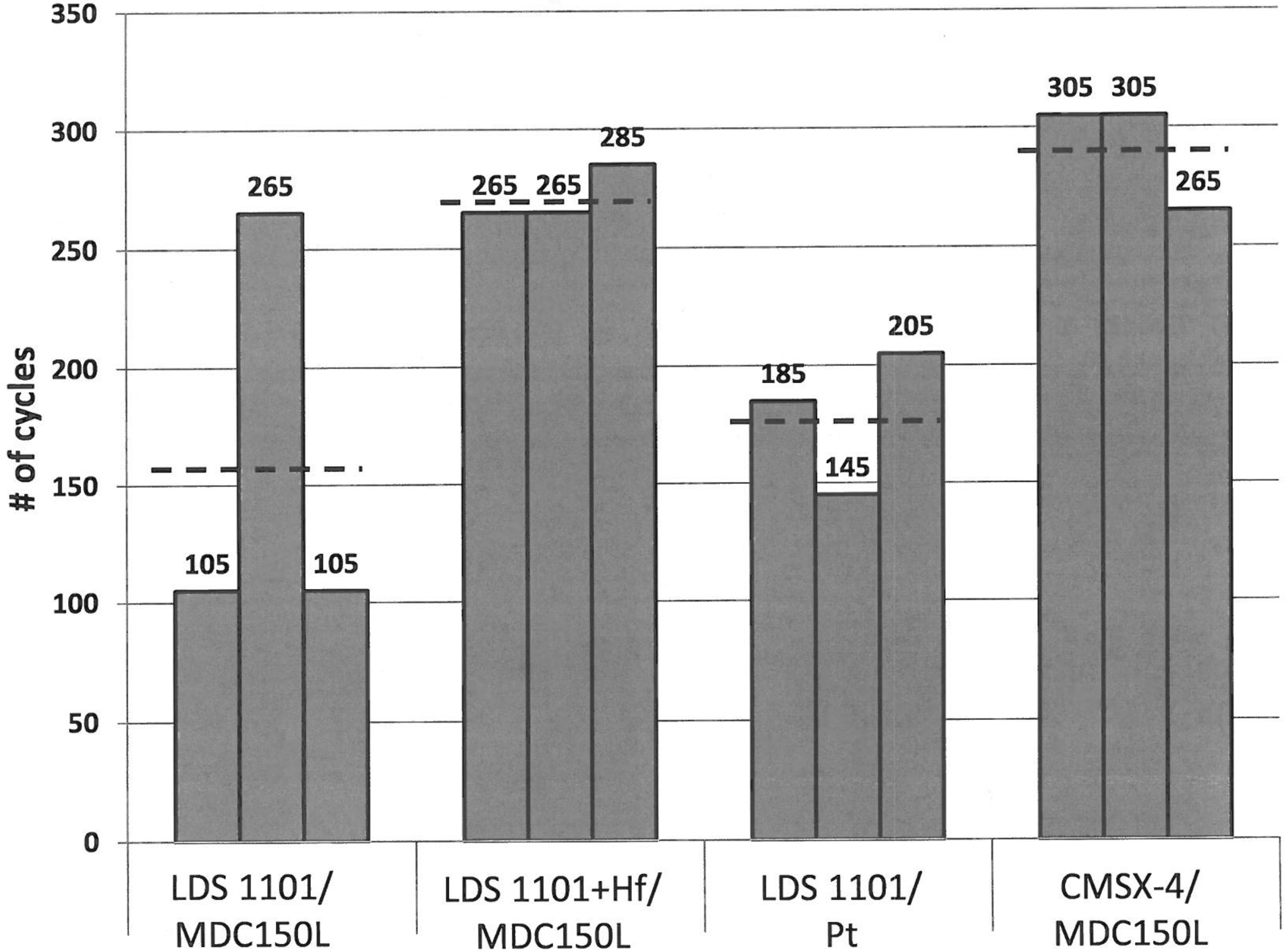


CMSX-4/MDC150L (265 1-hr cycles)

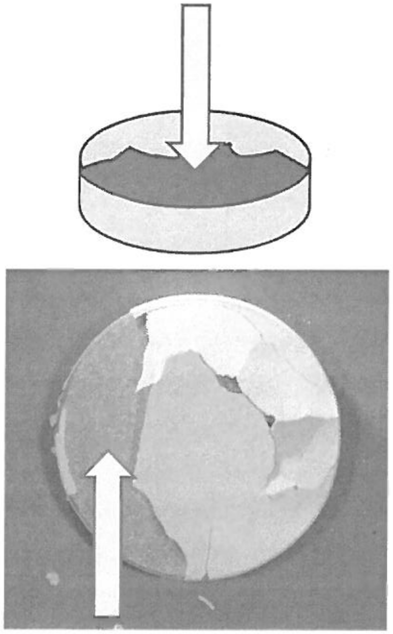


Results: TBC Lifetimes

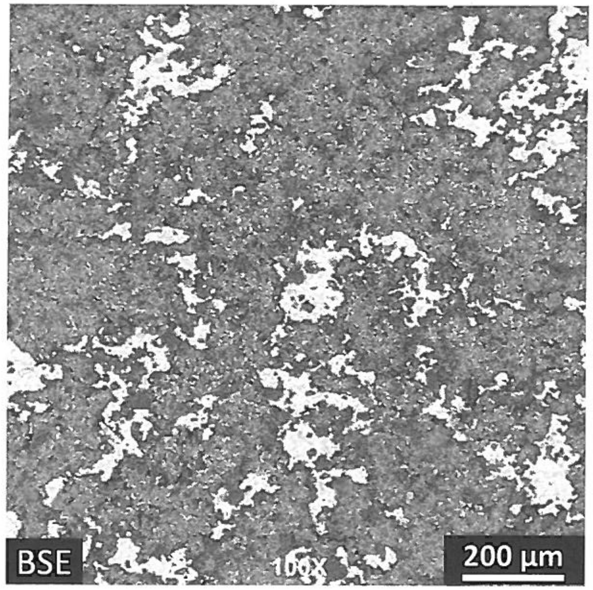
1-hr cycles at 1035°C



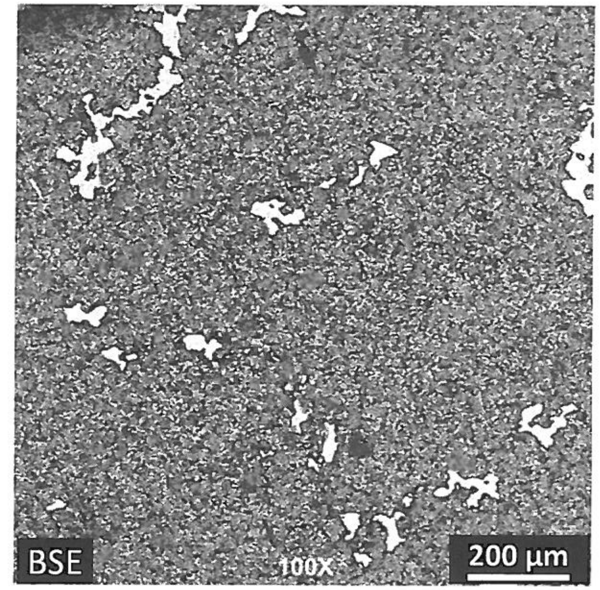
View of the surface after 7YSZ top coat delamination and spall



LDS1101 / MDC150L



LDS1101+Hf / MDC150L



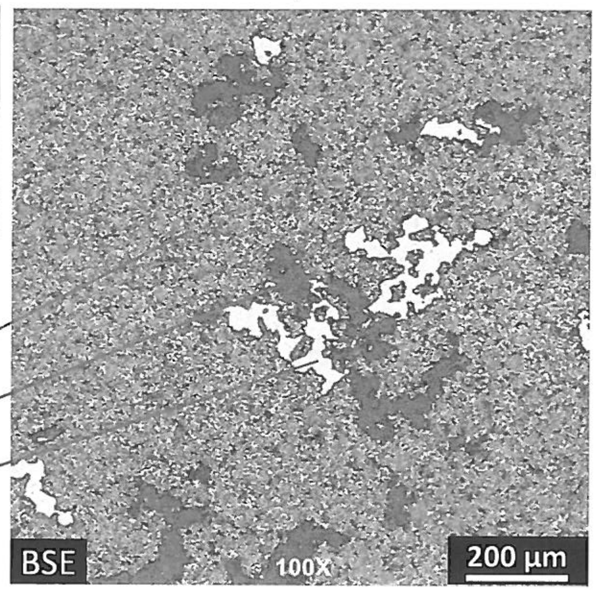
Morphology is similar for all three Pt aluminide bond coats, different for the Pt-only bond coat.

CMSX-4 / MDC150L

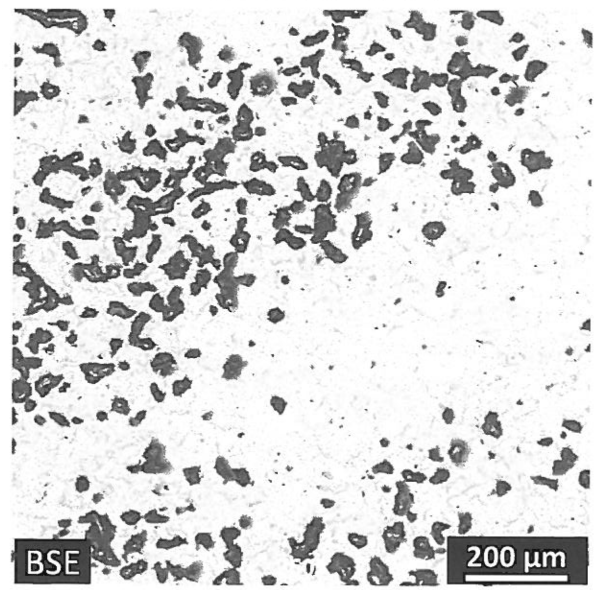
Mottled/speckled

Dark

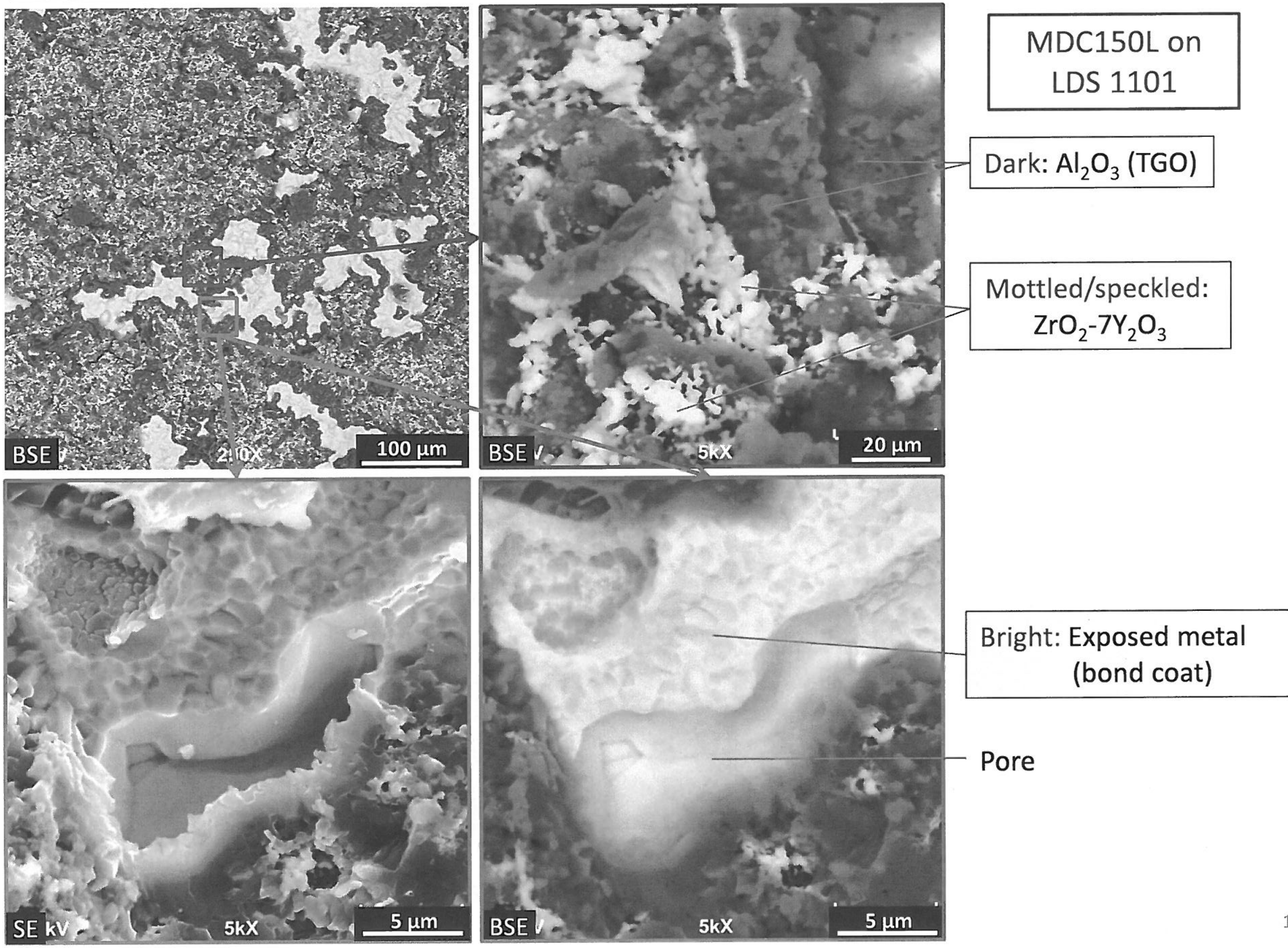
Bright



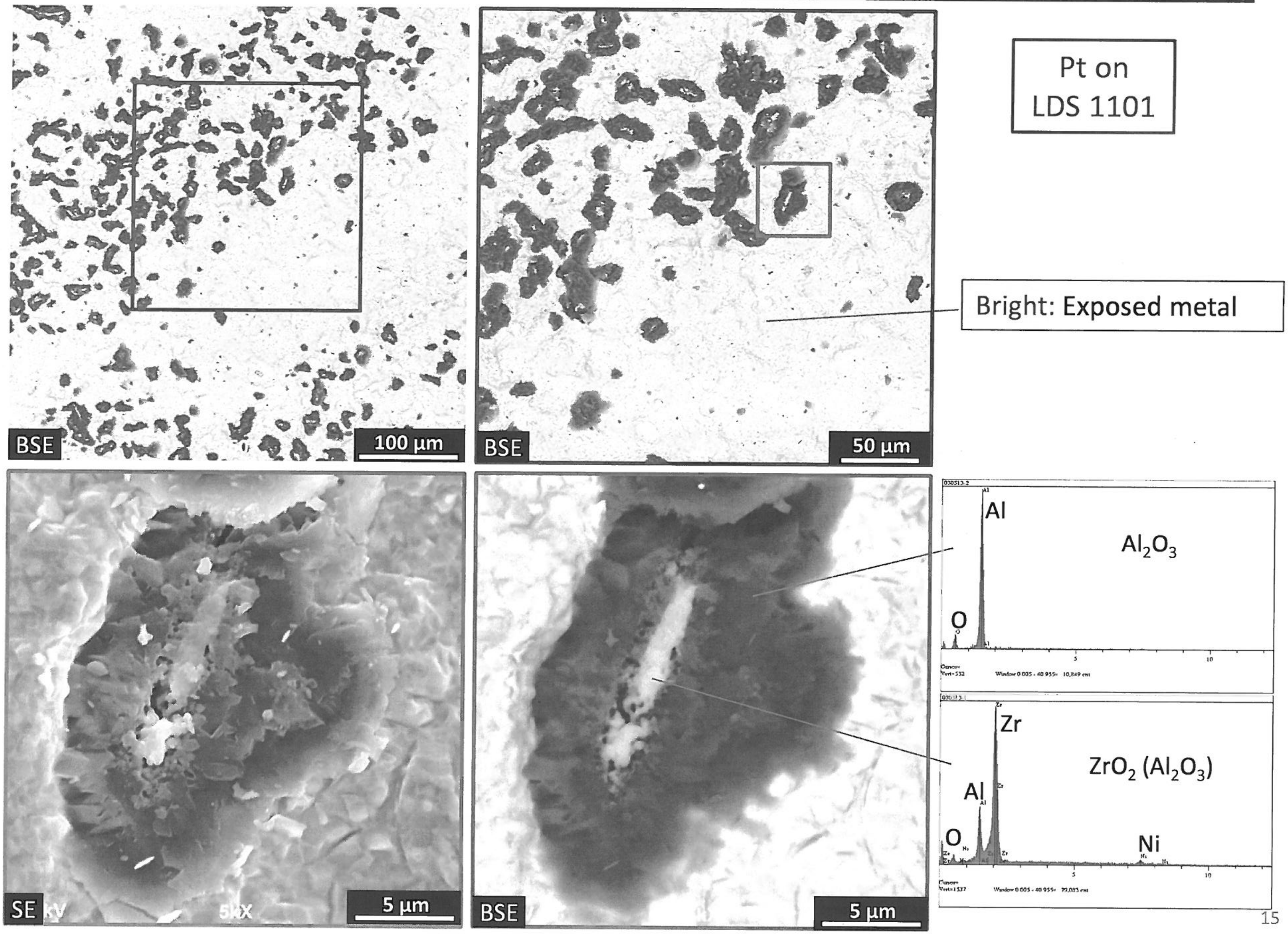
LDS 1101 / Pt



Magnified view of the exposed surface after 7YSZ top coat delamination and spall

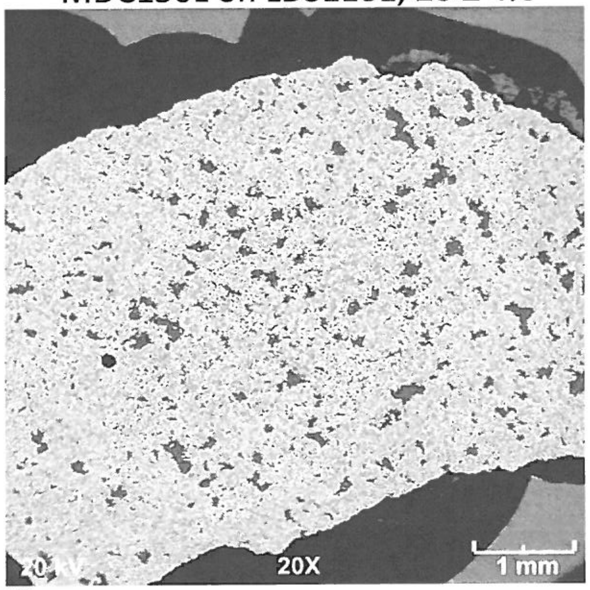


Magnified views of the exposed surface after 7YSZ top coat delamination and spall



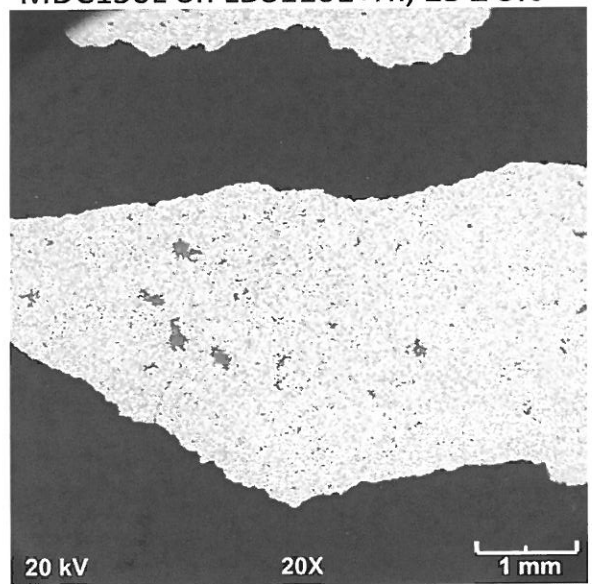
Underside of spalled 7YSZ top coat

MDC150L on LDS1101, 20 ± 4%

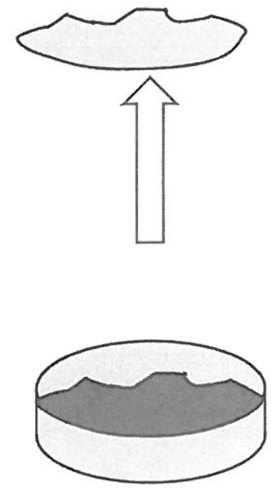


BSE

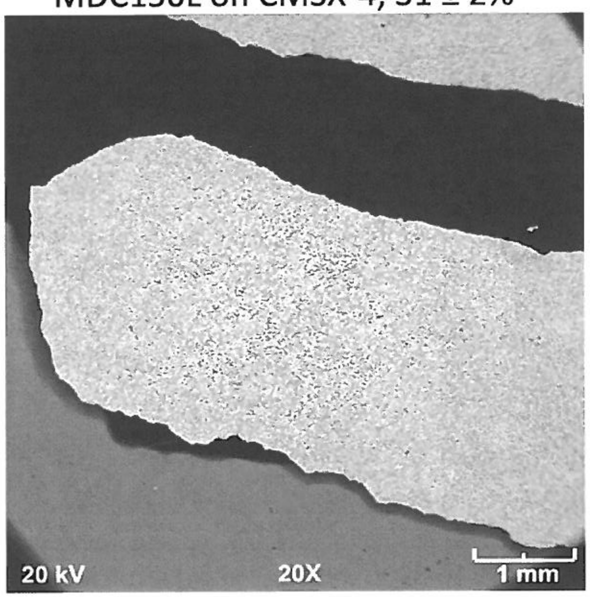
MDC150L on LDS1101+Hf, 23 ± 3%



BSE

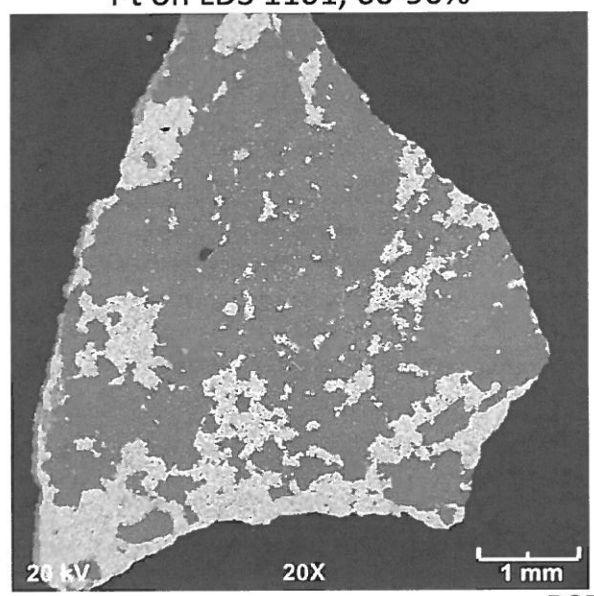


MDC150L on CMSX-4, 31 ± 2%



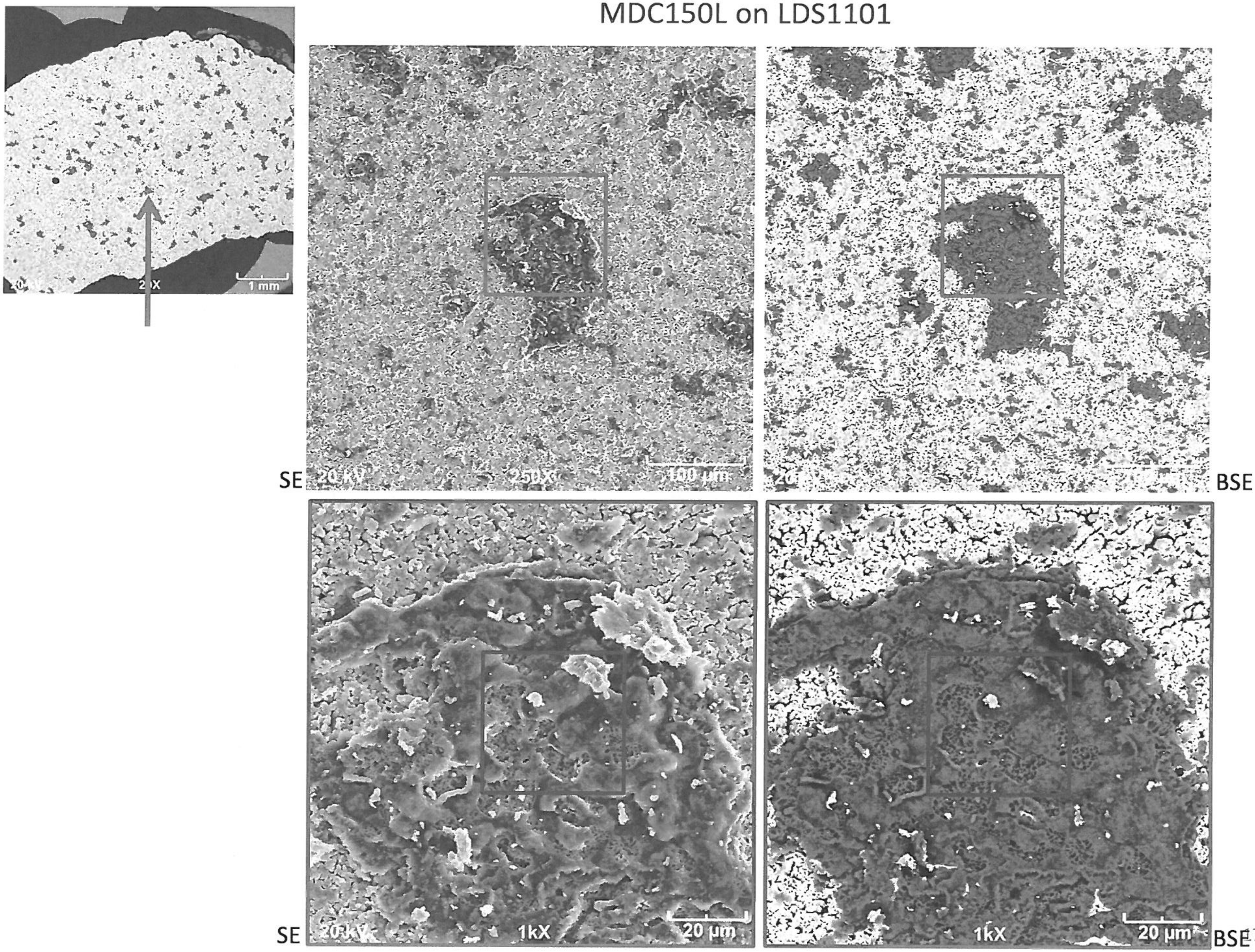
BSE

Pt on LDS 1101, 60-90%

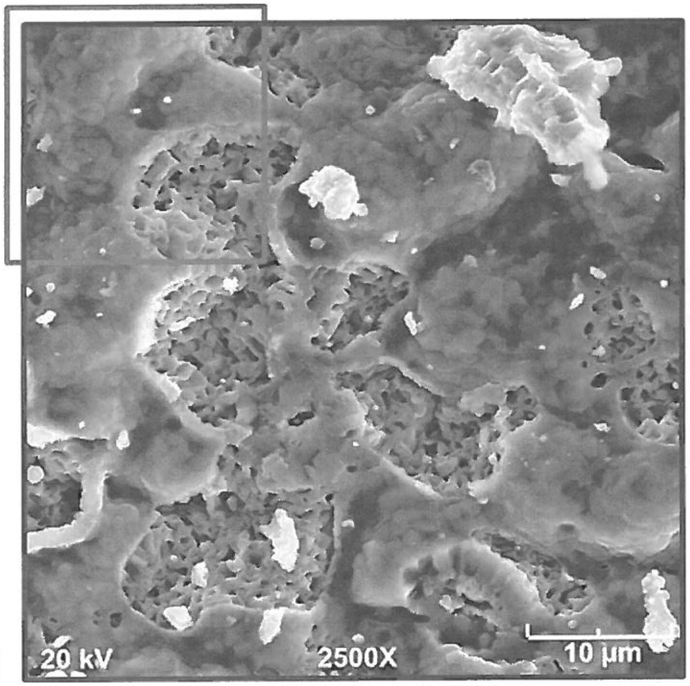


BSE

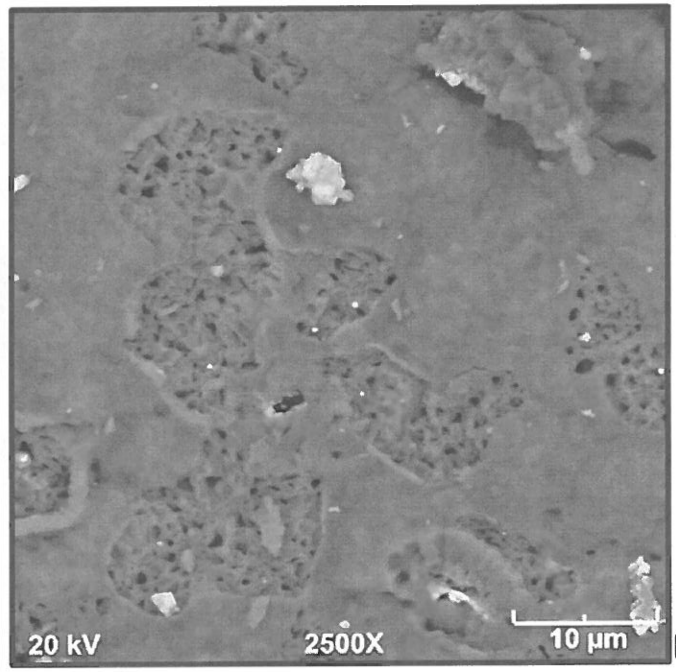
MDC150L on LDS1101



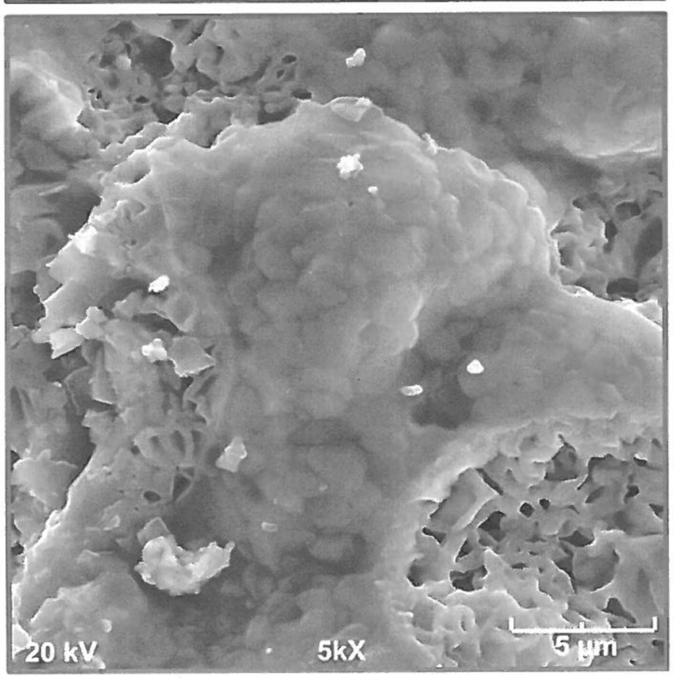
MDC150L on LDS1101



SE



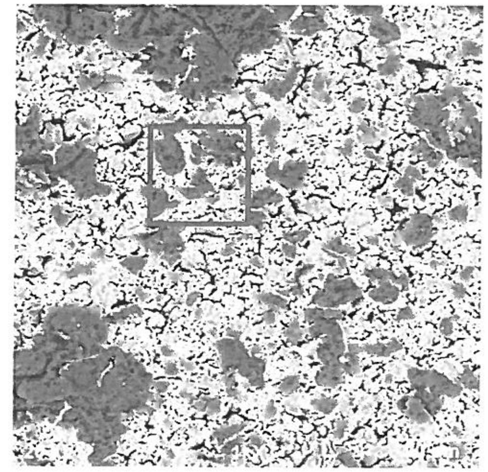
BSE

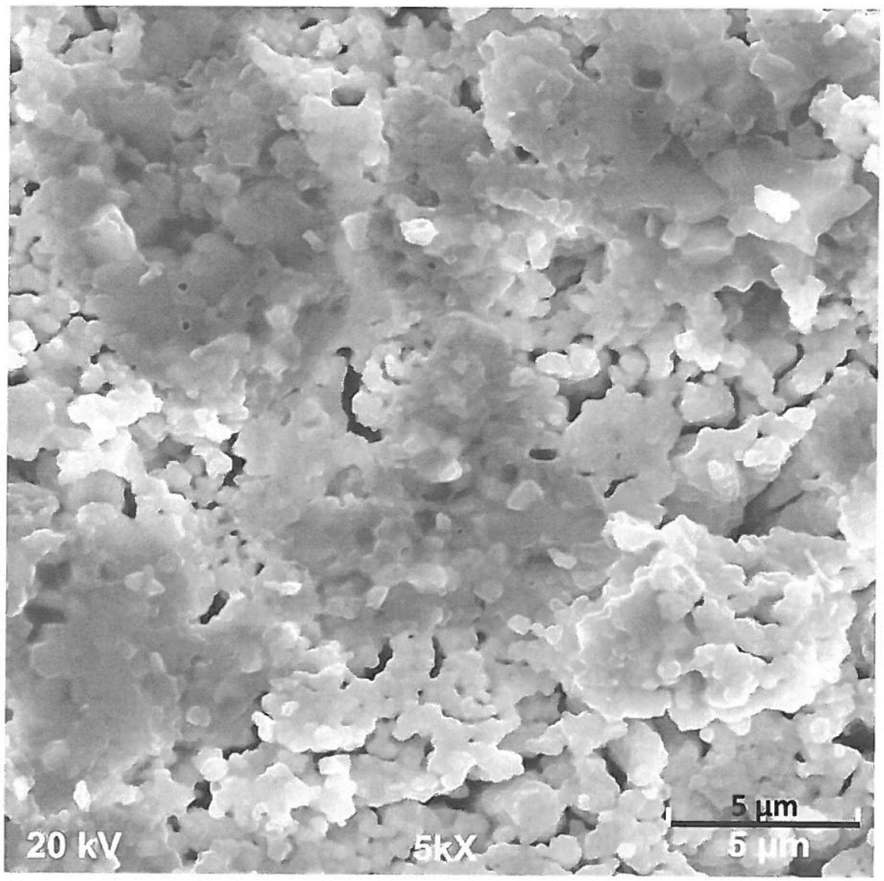


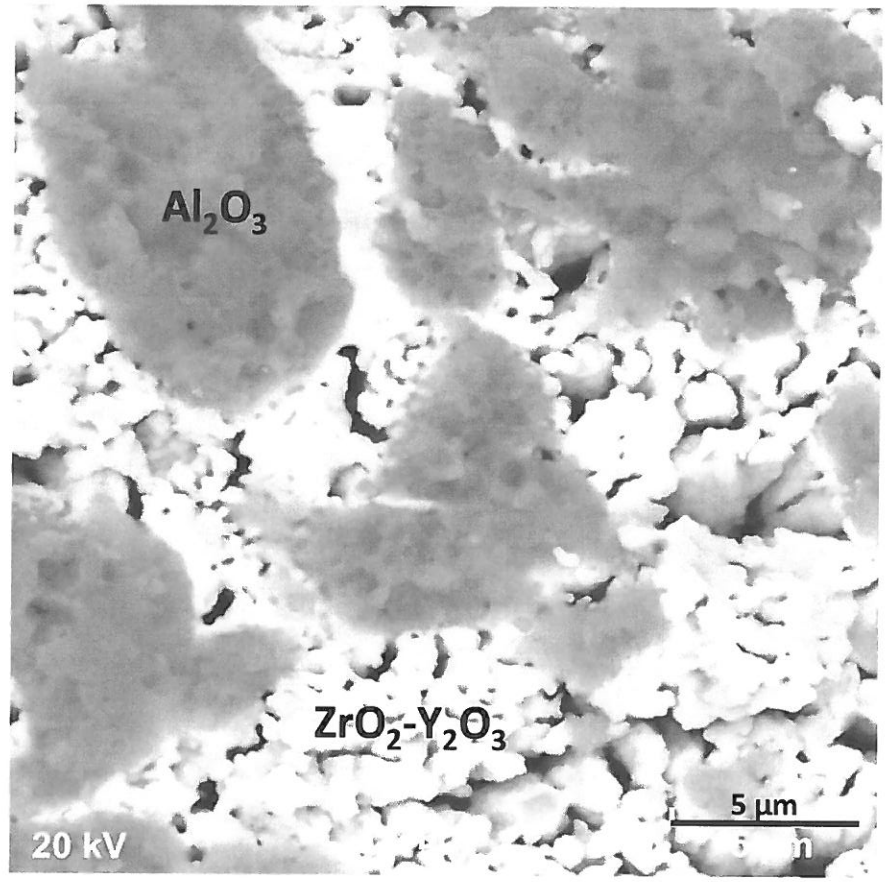
SE

- Large sections of attached alumina indicate fracture between alumina (TGO) and bond coat

- Small, thin sections of attached alumina indicate fracture primarily within the alumina (TGO)







Conclusions

- Addition of Hf increases the TBC lifetime in LDS alloys
  - Repeatability in TBC lifetimes for LDS 1101 without Hf raises questions

- LDS+Hf with Pt aluminide bond coat had higher TBC lifetime than LDS+Hf with Pt-only bond coat

- LDS+Hf with Pt aluminide coating had similar TBC lifetime and similar failure morphology to CMSX-4 (also contains Hf) with Pt aluminide coating

LDS superalloys have previously been shown to posses

high creep strength,

low density, and

good uncoated oxidation resistance.

The current study has shown that LDS superalloys containing (Y,Hf) exhibit similar TBC lifetimes as a commercial superalloy also containing (Y,Hf)

Acknowledgements

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